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DESIGN PROPOSAL FOR A COMPACT, SOLID-STATE, LOW-POWER KLYSTRON-PULSER FOR CTF3

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Abstract

A simple, compact, solid-state pulse generator using integrated gate commutated thyristors (IGCT's) is proposed for a low-power, pulsed L-band klystron system in the CLIC test facility CTF3 at CERN. This design uses an array of IGCT devices in series that discharge an energy storage capacitor network into a step-up pulse transformer. A pulse width of about 2.5 microseconds flat top is created at the transformer secondary winding for the klystron load, with a peak voltage of 70 kV and pulse current of ~50 A. The repetition rate of the pulser is designed for nominal 10 Hz operation.

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1. Introduction

A simple, compact, solid-state pulse generator using Integrated Gate Commutated Thyristors (IGCTs) has been designed for a low-power, pulsed L-band klystron system in the CLIC test facility CTF3 injector [1] at CERN. This design uses a series array of IGCT devices that discharge an energy storage capacitor network into a step-up pulse transformer. A 70 kV pulse of about 2.5 μs width is produced at the transformer output for the klystron load. The klystron is pulsed at 10 Hz and has a beam current of 36 A.

2. CTF3 drive-beam injector

The CTF3 drive-beam injector [2] includes a thermionic gun, three Sub-Harmonic Bunchers (SHBs), one pre-buncher (PB), one 6-cell travelling-wave buncher (B1) and two accelerating structures (ACS). The injector provides CTF3 with an electron beam of about 3.5 A at 25 MeV with bunches of <12 ps. All injector components downstream of the gun are embedded in a solenoidal field of about 1000 G. The klystron must produce >400 kW of peak RF power for the three SHBs at a frequency of 1.5 GHz. The other injector cavities operate at 3 GHz. Figure 1 shows the basic layout of the drive-beam injector.

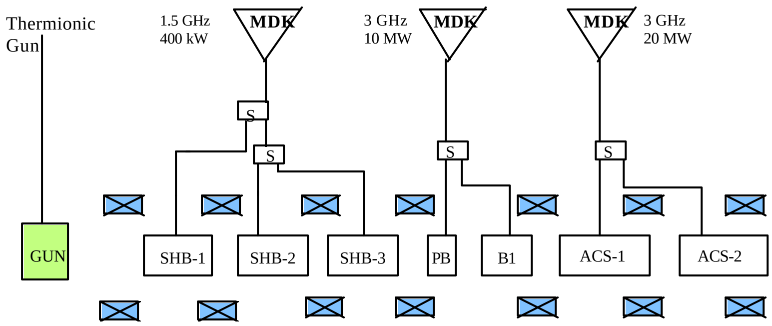

Figure 1: Schematic layout of CTF3 drive-beam injector

3. Wide-band Klystron

CTF3 will use the 3 GHz high-power klystron-modulators from the CERN LEP pre-injector linac. Each of these produces up to 35 MW peak-power and are used for the CTF3 drive-beam linac and the accelerating cavities in the injector. A new 400 kW, 1.5 GHz klystron being designed will power the SHBs. The parameters of the wide-band 1.5 GHz klystron [3] that will power the SHB cavities are given below in Table 1. The klystron will have an efficiency of only ≥ 20% due to the wide bandwidth requirements. This bandwidth is needed so that the input phase of the klystron can be switched rapidly (<10 ns) through 180^{o} every 140 ns, in order to produce a train of "phase-coded" sub-pulses within the 2 µs RF pulse. This action shifts alternate sub-pulses in time to synchronise them for the 1.5 GHz RF deflection and interleaving process that follows.

Parameters	Values	Units
Centre frequency	1500	MHz
Bandwidth (at -1dB)	≥ 150	MHz
Repetition frequency	10 (operational) 50 (test)	Hz
Peak output power	500 (400 min)	kW
Average power	12.5 (62.5)	W
RF pulse width	≥ 2.5	µs
Klystron beam voltage	69 (63)	kV
Klystron beam current	36 (32)	A
Perveance	2	µPerv.
Focusing field	640	G
Signal gain	≥ 30	dB

Table 1: Preliminary parameters for the 1.5 GHz wide-band klystron

4. Wide-band klystron Pulser

This klystron will require a low-power pulser that can probably be built from spare parts of the 3 GHz modulators. Because of space limitations it must be made compact. The basic electrical circuit of the pulser is given below in Figure 2, and the equivalent circuit used for modelling the performance of the klystron pulser is given in Figure 3. The main components that can be used concern the klystron tank assembly, where the pulse transformer and isolating inductor together with the toroidal heating transformer, are key elements in the pulser design.

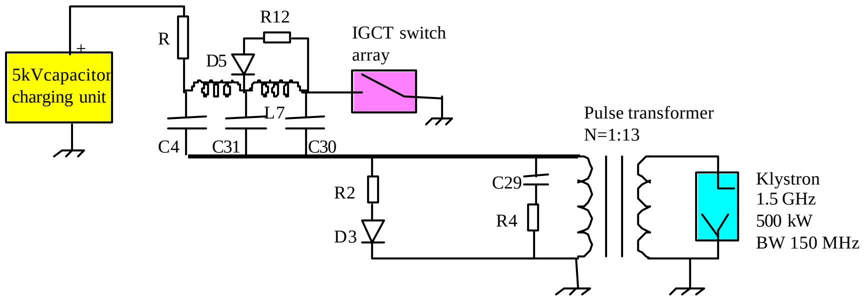

Figure 2: Basic klystron pulser circuit

All components in this equivalent circuit are referred to the primary side of the pulse transformer. The klystron appears as a non-linear diode-type load to the pulser and is a function of the applied beam voltage and the perveance. The referred klystron load R1 in the simulation circuit is given by:

$$R_{kly} = \frac{1}{p * N^{2} * \sqrt{V_{kly}}}$$

Where N is the pulse transformer step-up ratio and *p* is the klystron perveance in $A/V^{3/2}$. This klystron impedance is used in series with a diode in the simulation circuit. All pulse transformer values are from the existing high-power modulator. The transformer leakage inductance L41 is the referred secondary value plus the primary leakage inductance. The secondary winding stray capacity seen at the primary terminals is C28. The estimated klystron gun capacity is C27. The core loss is represented by R5. The transformer magnetising inductance is L42 and is considered constant for the small flux change during the pulse. The core bias isolation inductor is L43. Energy storage for the pulse is made with two 60 μF, 5 kV capacitors in parallel. A coupling inductor L7 together with the front-end capacitor C30 improves the pulse rise time response. The klystron is protected from any inverse cathode voltage by the D3 and R2 network.

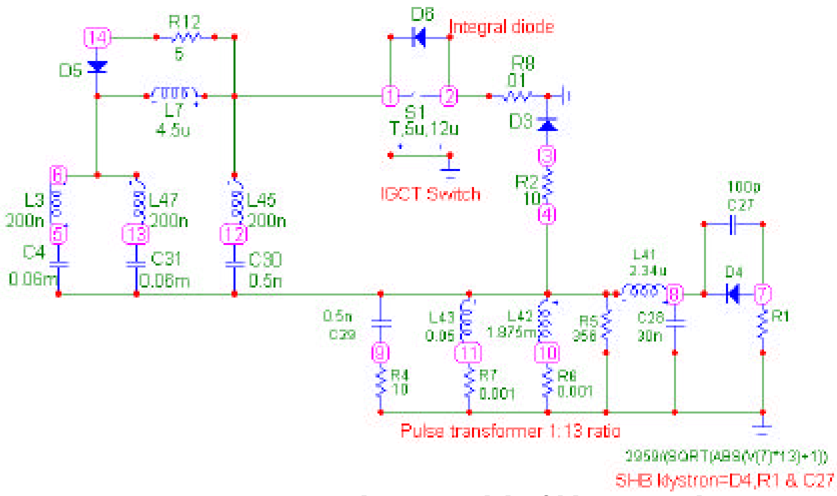

Figure 3: Simulation model of klystron pulser

In operation, the IGCT switch is triggered on and the positive rail is pulled to ground allowing the opposite terminal to swing the primary winding negative until the IGCT is switched off at the end of the pulse. The simulation waveforms of the klystron voltage and IGCT switch current are shown in Figure 4. The storage capacitors, cell inductor and IGCT switch are smaller than the pulse forming network (PFN) in the original modulator, and operates at only 5 kV, reducing insulation requirements and component cost.

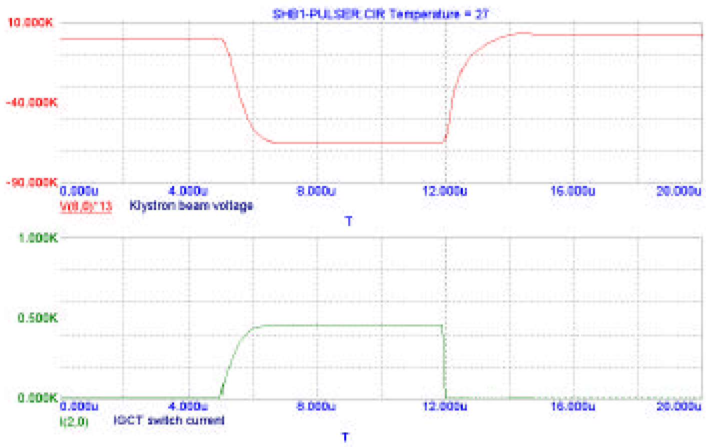

Figure 4: Simulation waveforms of klystron pulser

The semiconductor switch [4] proposed is the IGCT from ABB shown in Figure 5. This device has low switching and on-state losses, requires no snubber components and has an integrated diode and control gate circuitry to reduce the parts count. Unlike the Insulated Gate Bipolar Transistor (IGBT), the IGCT turn-off is not gate-current controlled and its performance is enhanced by the integrated opto-triggered gate-driver, so that it behaves like a true on-off switch. The 91 mm diameter devices chosen have a nominal blocking voltage of 4500 V with a 3500 A turn-on/off current capability. For reliability, a stack of four units is used since the permanent DC voltage that reduces the failure rate due to ambient cosmic radiation at sea level is only 2800 V. The main parameters of the klystron pulser are in Table 2.

Figure 5: An IGCT switch module and driver circuitry

Parameter	Value	Units
Primary capacitor voltage	5	kV
Peak IGCT pulse current	450	A
Pulse voltage rise time(10-90%)	800	ns
Flat top voltage deviation over 2 μs pulse width	0.3	%
IGCT DC voltage for 100 FIT failure rate	2800	V

Table 2: Pulser parameters

5. Conclusion

A compact pulser circuit is proposed that uses components common to existing high power modulators, but has an IGCT semi-conductor switch array instead of a thyratron. Simulation results show that it produces a good pulse shape with a small amount of droop over the pulse width. A low-inductance capacitor network replaces a PFN that eliminates any flat top ripple, and consequently any phase ripple at the wide-band klystron output.

6. References

[1] L. Rinolfi (Ed),“Proc. 5th CTF3 Collaboration Meeting, CERN 26-27Oct. 2000”, CLIC Note 464.

[2] F. Zhou & H. Braun, “Updated Beam Dynamics for a CTF3 Injector”, CTF3 Tech Note 2000-15,2000.

[3] P. Pearce, “Specification for a feasibility study of a broad-band klystron for the CLIC test facility (CTF3) to operate at a frequency of 1.5 GHz”, CERN PS/LP Note 2000-003 (Spec), 2000.

[4] ABB Semiconductors, “Special components for pulsed power applications,” 05-99, 1999.